Ocean Reference Stations

Robert A. Weller, Albert J. Plueddemann
Woods Hole Oceanographic Institution, Woods Hole, MA

Project Summary

The goal of this project is to maintain long-term surface moorings, known as Ocean Reference Stations, as part of the integrated ocean observing system. The scientific rational for these Ocean Reference Stations is to collect long time series of accurate observations of surface meteorology, air-sea fluxes, and upper ocean variability in regions of key interest to climate studies and to use those data to quantify air-sea exchanges of heat, freshwater, and momentum, to describe upper ocean variability and describe the local response to atmospheric forcing, to motivate and guide improvement to atmospheric, oceanic, and coupled models, to calibrate and guide improvement to remote sensing products and capabilities, and to provide anchor point for the development of new, basin scale fields of the air-sea fluxes. Model, satellite, and climatological fields of surface meteorology and air-sea fluxes have large errors; high quality, in-situ time series are the essential data needed to improve our understanding of atmosphere-ocean coupling and to build more accurate global fields of air-sea fluxes. Prediction and analysis of climate variability based on model or other products that have large errors in their atmosphere-ocean exchanges of heat, freshwater, and momentum is flawed; this effort to collect the critical in-situ flux time series and related efforts to develop air-sea flux products that use these Ocean Reference Stations as anchor points aim to remedy these flaws and greatly improve our understanding of how the atmosphere and ocean are coupled and together influence climate. This project is now maintaining these Ocean Reference Stations at three key locations: the site at 20°S, 85°W under the stratus cloud deck off northern Chile (Stratus), the Northwest Tropical Atlantic Station (NTAS) at 15°N, 51°W, and a site north of Hawaii near the Hawaii Ocean Timeseries (HOT) site. The surface buoys are equipped with ASIMET (Air-Sea Interaction Meteorological systems) developed at WHOI and capable of climate-quality measurements once per minute for one year. Telemetered near-real time data are provided to numerical weather prediction centers (but not included in their model runs, thus providing an independent means to examine model performance); these data are used to investigate model errors

and biases and test improvements to the models. Data are also provided to validate remote sensing products and to guide development of new flux products. In addition, these data support research done by NOAA and other climate studies and these Ocean Reference Stations are coordinated with other flux reference sites.

Accomplishments

The project is managed as four Tasks, with accomplishments reported by task.

Task I: Engineering, oversight and data:

All three sites are now occupied by the modular-hull buoy (Fig. I-1). Hourly meteorological data are transmitted in near-real time via Argos telemetry and made available on an FTP server and a website with download capability. Data processing continues on schedule. The "best" quality meteorological and flux data is being made accessible through the web, typically within a year of recovery. Testing of Iridium data telemetry hardware was begun on WHOTS and worked successfully.

Figure I-1: The old rigid hull (left) and the new modular buoy (right). Photo taken during the December 2004 Stratus deployment and recovery cruise.

Task II: Stratus Site:

The stratus surface mooring was originally deployed in October 2000. It has been annually redeployed and recovered since that time, including the most recent done during the October 8-27, 2006 cruise of the NOAA Ship *Ronald H. Brown*. Accurate prediction of cloud amount and cover in marine stratus regions has long been a challenge; this is true off Peru and northern Chile. Further, model studies point to the dependence of the coupled climate variability of the Pacific Basin and surrounding continents to the atmosphere-ocean coupling in the stratus region. Thus, establishment and maintenance of an Ocean Reference Station in this critical but data sparse area has been a high priority.

Data recovery this year was good, post-calibrations are being done, and data files have been shared with colleagues. On the buoy we measure air temperature, sea surface temperature, relative humidity, incoming shortwave and longwave radiation, wind speed and direction, rain rate, and barometric pressure. On the mooring line the instrumentation is concentrated in the upper 300m and measures temperature, salinity, and velocity. Hourly surface meteorological data are archived at WHOI, arriving within hours of when it was observed. These data are exchanged in near real time with ECMWF and NCEP; they in turn provide operational data at the grid point nearest the model. It is also shared with the Chilean Navy (SHOA). The same data are shared with CLIVAR investigators, especially modelers interested in the Stratus region and VAMOS/VOCALS investigators in the U.S. and in South America. This meteorological data are used to assess the realism of operational atmospheric models in the stratus region. Once per minute as well as hourly surface meteorological time series are provided to the VOCALS and other investigator communities (including Sandra Yuter, Chris Bretherton, Meghan Cronin) after recovery. The surface meteorological data have been made available to the satellite community (including radiation – Langley, winds – Remote Sensing Systems and JPL, SST – Dick Reynolds, all variables – the SEAFLUX project).

The oceanographic data are being used by Weller at WHOI to investigate air-sea coupling and upper ocean variability under the stratus deck. The initial archive is maintained by the Upper Ocean Processes Group at WHOI, which runs a public access server for their mooring data. We are providing the data to Ocean SITES (http://www.oceansites.org). We are collaborating with the Baseline Surface Radiation Network (BSRN) and the GEWEX (Global Energy and Water Cycle Experiment) Radiation Panel. Long time series of incoming radiation along with the other coincident surface meteorological observations are very rare in the open ocean. The accuracy of the ORS radiation data has made them of high value for development of improved estimates of surface radiation fields over the oceans.

The Stratus ORS has been occupied since October 2000. We are now able (see Table II-1, for example) show how far climatological means of the air-sea fluxes, such as those computed from the 40-year ECMWF reanalysis (ERA-40), are incorrect in their representation of the atmosphere-ocean coupling under the very important stratus deck region off northern Chile. The ocean there receives more heat than ERA-40 suggests but the sky is cloudier (lower mean shortwave) than ERA-40 suggests. The additional gain comes from the observed latent, sensible, and longwave heat fluxes being smaller than indicated by the ERA-40 climatology. As an example of our collaboration with modeling centers, ECMWF retrieves our buoy data and does offline runs of modifications of the their atmospheric model to explore how to improve the realism of their model under the stratus clouds.

Variable	Stratus 1	Stratus 2	Stratus 3	Stratus 4	Stratus 5	ECMWF
Latent	-103.1	-118.0	-107.3	-99.0	-99.5	-124.6
Sensible	-7.0	-10.3	-7.1	-7.1	-5.0	-15.2
Longwave	-40.6	-49.2	-36.6	-21.7	-44.6	-55.0
Shortwave	202.0	199.5	190.4	191.3	183.5	220.2
Net	51.4	22.1	39.4	63.4	34.3	25.5

Table II-1: Year-long means of the latent, sensible, longwave, shortwave, and net heat fluxes (net is the sum of the first four, where a positive sign indicates the ocean is being heated) from the first 5 deployments of the Stratus ORS compared to the 40-year mean ECMWF reanalysis values of these heat fluxes.

The Stratus cruises serve the wider scientific community by providing a platform on which to study the regional ocean. Additional researchers who participated in collaborative research or benefited from shared ship time in FY2007 have come from many institutions: NOAA Environmental Technology Laboratory, Servicio Hydrografico y Oceanografico de la Armada (SHOA, Chile), University of Concepcion (Chile), University of Hawaii, University of Buenos Aires, and University of Miami. The 2006 stratus cruise also hosted a teacher from NOAA’s Teachers-at-Sea program (Brett Hoyt). The work this year included servicing the Chilean Navy tsunami warning installation; this tsunami warning installation was recovered and a new one deployed for the Chilean Navy. The deployment marked the beginning of a growing partnership between the ORS project and SHOA. We installed self-recording ASIMET modules on the tsunami buoy and temperature and temperature/salinity recorders on the buoy’s mooring line (Fig. II-1). This also marks the beginning of the use of a tsunami mooring for climate observations.

We supported the participation of a student from the University of Buenos Aires, Argentina as a further effort at outreach and capacity building; this student works for Dr. Alberto Piola who is at both the University of Buenos Aires and at the Argentine Navy equivalent of SHOA. We have invited the student and Dr. Piola to visit our group at

WHOI to explore further collaboration with Argentina in developing the global array of ORS.

Figure II-1: Chilean Navy (SHOA) DART buoy equipped with WHOI meteorological sensors.

Task III: NTAS Site:

The Northwest Tropical Atlantic Station (NTAS) project for air-sea flux measurement was conceived in order to investigate surface forcing and oceanographic response in a region of the tropical Atlantic with strong SST anomalies and the likelihood of significant local air-sea interaction on seasonal to decadal time scales. The strategy is to maintain a meteorological measurement station at approximately 15^{o} N, 51^{o} W through successive (annual) turn-arounds of a surface mooring. Redundant meteorological systems measure the variables necessary to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas.

NTAS has two primary science objectives: 1) Determine the air-sea fluxes of heat, moisture and momentum in the northwest tropical Atlantic using high-quality, in-situ meteorological measurements from a moored buoy. 2) Compare the in-situ fluxes to those available from operational models and satellites, identify the flux components with the largest discrepancies, and investigate the reasons for the discrepancies. An ancillary objective is to compute the local (one-dimensional) oceanic budgets of heat and momentum and determine the degree to which these budgets are locally balanced.

A mooring turn-around cruise was conducted on the NOAA ship *Ronald H. Brown* February 2006 in order to retrieve the existing mooring (NTAS-5, deployed 11 March 2005) and replace it with a new mooring (NTAS-6). In preparation for this cruise, three Air-Sea Interaction Meteorology (ASIMET) systems were calibrated and tested, and two systems, comprised of the best performing sensors, were prepared for deployment. The NTAS-6 mooring was deployed on 25 February 2006 and the NTAS-5 mooring was recovered on 28 February. The period between deployment and recovery was dedicated to a comparison of the two buoy systems, with the shipboard system as an independent benchmark. Data return was good, with all sensors showing 90-100% data return except for wind, which had just under 50% return on one system. Since the second system had 100% return for wind, no data will be missing in the combined record.

The 2006 NTAS cruise represented the start of a collaboration with the National Data Buoy Center (NDBC) wherein the newly established NDBC west and middle Atlantic sites (41040 and 41041) were serviced. The 2006 cruise also included the deployment of 7 ARGO floats at the request of NOAA AOML, and a bathymetric survey offshore of Barbados at the request of the US Embassy in Barbados and in support of work being done by the Barbados Coastal Zone Management Unit.

Evaluation of NTAS surface meteorology in conjunction with our volunteer observing ship (VOS) data from the Atlantic and nearby NDBC buoys has been initiated. The goal is to determine the appropriate spatial “footprint” for the buoy meteorology on various time scales. Auto-correlation times for both buoy and VOS meteorological variables are from 3-6 h. Barometric pressure, dominated by the semidiurnal atmospheric tide, and shortwave radiation, dominated by the diurnal cycle, show the most consistent results. The VOS variables show variability on time scales of hours that is not seen in the buoy records, and is attributed to spatial variability. Cross-spectra of NTAS vs. an NDBC buoy 200 km to the west show that coherence begins to increase on 3-5 day synoptic weather scales, and is significant for all variables at 10 days and longer (Fig. III-1, left). Significant coherence is also seen near 12 and 24 h periods relating to the diurnal cycle and the atmospheric tide. The short duration (1 day) of the VOS records near the buoy do not allow coherence on synoptic weather scales to be evaluated. Cross-spectra of NTAS vs. the VOS passing 300-500 km to the west show significant correlation for barometric pressure and shortwave radiation, significant, but weak correlation for SST and wind at the longest resolved periods (near 24 h), and no significant correlation for other variables (Fig. III-1, right).

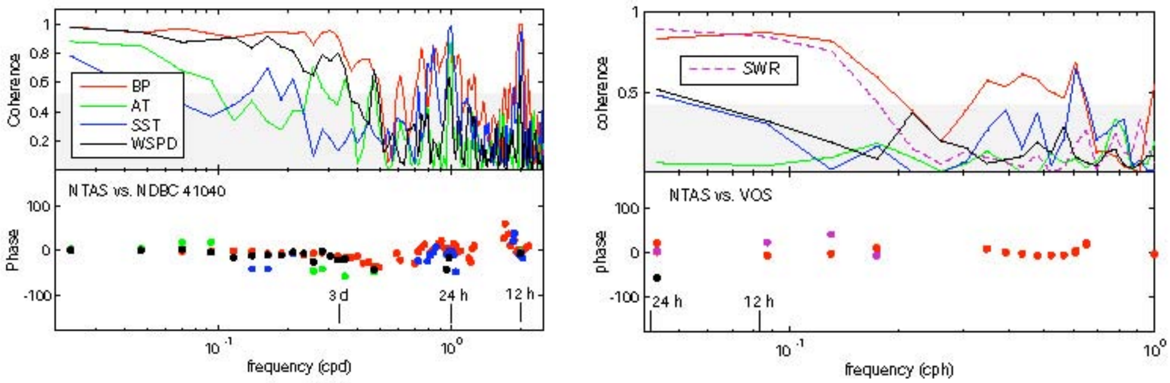

Figure III-1: Coherence and phase from cross-spectra of NTAS meteorological variables vs. the same variables on NDBC 41040 (200 km to the west) and the VOS Merkur (six passes 300-500 km to the west).

Task IV: Hawaii Site:

The Hawaii Ocean Time-series (HOT) site, 100 km north of Oahu, Hawaii, has been occupied since 1988 as a part of the World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JGOFS). Among the HOT science goals are to document and understand seasonal and interannual variability of water masses, relate water mass variations to gyre fluctuations, and develop a climatology of high-frequency physical variability in the context of interdisciplinary time series studies. The primary intent of the WHOI Hawaii Ocean Timeseries Station (WHOTS) mooring is to provide long-term, high-quality air-sea fluxes as a coordinated part of the HOT program and contribute to the goals of observing heat, fresh water and chemical fluxes at a site representative of the oligotrophic North Pacific Ocean. It is expected that establishment of the WHOTS mooring will accelerate progress toward understanding multidisciplinary science at the site, provide an anchor site for developing air-sea flux fields in the Pacific, and provide a new regime in which to examine atmospheric, oceanic, and coupled model performance as well as the performance of remote sensing methods.

The observational strategy is to maintain a surface mooring at approximately 22.75° N, 158° W, instrumented to obtain meteorological and upper ocean measurements, through successive (annual) turnarounds done in cooperation with HOT investigators. Redundant meteorological systems on the surface buoy measure the variables necessary to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas. Subsurface oceanographic sensors on the mooring are being provided through cooperation with Roger Lukas (U. Hawaii; funded by the National Science Foundation).

A mooring turn-around cruise was conducted in June 2006 on the Scripps ship *Revelle*. In preparation for this cruise, three Air-Sea Interaction Meteorology (ASIMET) systems were assembled and tested. The WHOTS-2 mooring was recovered on 24 June 2006 and the WHOTS-3 mooring was deployed on 26 June. Periods of about 24 hours prior to the WHOTS-2 recovery and after the WHOTS-3 deployment were dedicated to an intercomparison of the buoy and shipboard meteorological systems. The intercomparison last year showed evidence of diurnal heating effects suggesting that some sensor positions on the 2.7 m buoy tower were suboptimal. For the WHOTS-3 buoy, mounts for air temperature/relative humidity sensors were extended, and no evidence of this heating was seen. Commercial bird-prevention spikes were installed on the WHOTS-3 buoy to reduce contamination and shadowing due to birds. A cruise report is in preparation.

The WHOTS-2 mooring was used as a test-bed for implementation of an Iridium data telemetry system, developed under the ORS Engineering, Oversight and Data project. Initial results indicate that the system worked well, and the WHOTS-3 buoy was deployed with two such Iridium systems as a further test. Additional systems based on the WHOTS design are now being developed for the telemetry of subsurface data on NTAS and Stratus.

Preliminary processing of the WHOTS-1 meteorological data has been completed and that of WHOTS-2 has begun. Data return was good. The hourly Argos and Irdium data are available on-line from the Upper Ocean Processes (UOP) group web site (http://uop.whoi.edu/projects/WHOTS/whots.htm). Daily surface temperatures and fluxes (Fig. IV-1) show relatively strong, episodic cooling in the winter of 2004/2005 due to strong wind events and large air-sea temperature differences. Warming the following spring and summer was more steady, leading to maximum surface temperatures in late August 2005. The contribution of the surface fluxes to the local heat and momentum balance will be assessed in cooperation with Lukas, who is analyzing the first two years of subsurface data from the WHOTS moorings (Fig. IV-2).

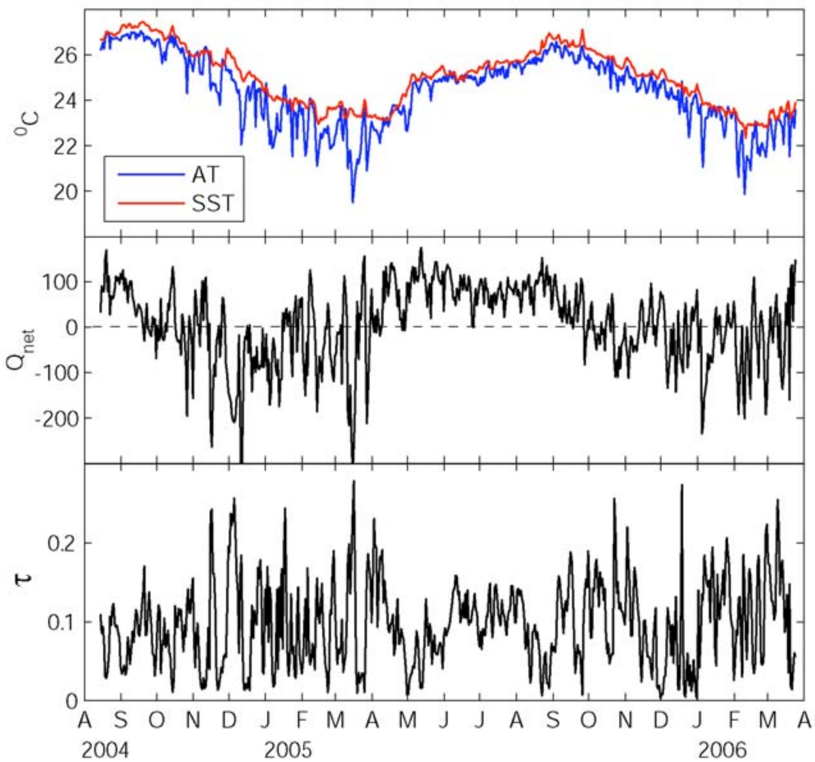

Figure IV-1: Surface conditions and fluxes from WHOTS-1 and 2. Daily values of air temperature and sea surface temperature (upper), net heat flux (middle) and wind stress (lower) are shown from preliminary processing of meteorological data from the WHOTS buoys.

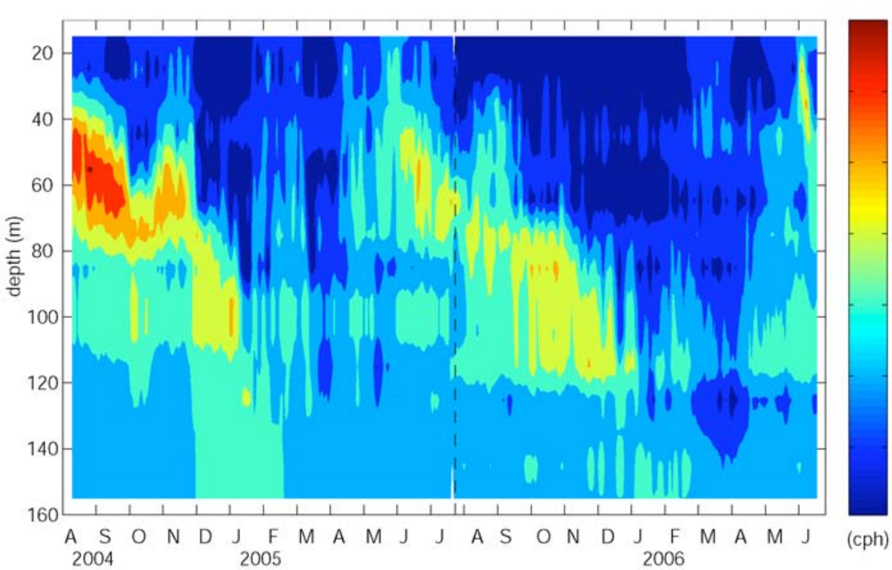

Figure IV-1: Contours of buoyancy frequency vs. depth and time from the WHOTS 1 and 2 moorings. Data from temperature/conductivity sensors, vector measuring current meters, and an acoustic Doppler current profiler are combined to compute the buoyancy frequency (figure courtesy of Roger Lukas, U. Hawaii).

Publications and Reports:

Colbo, K., R. Weller, J. Lord, J. Smith, P. Bouchard, C. Fairall, D. Wolfe, E. Serpetzoglou, A. G. V. Tisandie, J. F. S. Bustos, F. Bradley, and J. Tomlinson 2005: Stratus Ocean Reference Station (20^o S, 85^o W), Mooring Recovery and Deployment Cruise: R/V *Ronald H. Brown* Cruise 12-04, December 5 – December 23, 2004. Woods Hole Oceanogr. Inst. Tech. Rept., WHOI-2005-06.

Colbo, K and R. A. Weller, 2006: The variability and heat budget of the upper ocean under the Chile-Peru stratus. *J. Mar. Res*., in review.

Colbo, K. and R. A. Weller, 2006: The accuracy of the IMET sensor package. *J. Atmos. Oceanic Technol.*, in review.

Cronin, M. F., N. A. Bond, C. W. Fairall, and R. A. Weller, 2006: Surface Cloud Forcing in the East Pacific Stratus Deck/Cold Tongue/ITCZ Complex. *J. Climate*, **19**, 392-409, doi: 10.1175/JCLI3620.1.

Galbraith, N., A. Plueddemann and R. Weller, 2005. Near real time telemetry of surface meteorology from ocean reference stations, *Argos International Users Conference*, 5 - 7 April, Annapolis, Maryland (abstract).

Hutto, L., R. Weller, J. Lord, J. Smith, P. Bouchard, C. Fairall, S. Pezoa, L. Bariteau, J. Lundquist, V. Ghate, R. cstro, and C. Cisternas, 2006: Stratus Ocean Reference Station (20^o S, 85^o W), Mooring Recovery and Deployment Cruise: R/V *Ronald H. Brown* Cruise 05-05, September 26 – October 21, 2005. Woods Hole Oceanogr. Inst. Tech. Rept., WHOI-2006-06.

Plueddemann, A.J., R.A. Weller, R. Lukas, J. Lord, P.R. Bouchard and M.A. Walsh, 2006. WHOI Hawaii Ocean Timeseries Station (WHOTS): WHOTS-2 Mooring Turnaround Cruise Report. *WHOI Tech. Rept. WHOI-2006-08,* 67 pp.

Plueddemann, A.J., W.M. Ostrom, N.R. Galbraith, P.R. Bouchard B.P. Hogue, B.R. Wasnewski and M.A. Walsh, 2006. The Northwest Tropical Atlantic Station (NTAS): NTAS-4 Mooring Turnaround Cruise Report. *WHOI Tech. Rept. WHOI-2006-09*, 65 pp.

Plueddemann, A.J. F. Bahr, R.A. Weller and D. Hosom, 2006. Surface Meteorology from volunteer observing ships, *NOAA Office of Climate Observation Workshop*, 10-12 May 2006, Silver Spring, MD (poster).

Plueddemann, A.J. and R.A. Weller, 2005. Meteorology and air-sea fluxes from ocean reference stations, *NOAA Office of Climate Observation Workshop*, 25-27 April 2005, Silver Spring, MD (talk).